

eMagin Corporation (formerly FED Corporation)

Field Emission Displays Combine Benefits of Cathode-Ray Tubes and Flat-Panel Displays

In 1993, flat-panel displays (FPDs) were considered the most important competitive product in the electronics industry. The advent of low-cost FPDs was expected to usher in a host of new electronics applications, particularly high-definition television. Existing FPDs were lightweight and compact, but they had poor contrast and slow image refresh speeds; moreover, they were harder to read than the established cathode-ray-tube (CRT) displays. FED Corporation was a start-up company that was pioneering a new method for producing FPDs called field emission display. Field emission display would blend the lightweight and compact features of existing FPDs with the speed, brightness, and image quality of CRTs. In order to create the image, rows of tiny emitters fired electrons across a minute vacuum gap onto a phosphor coating. However, the vacuum was difficult to maintain. FED applied to the Advanced Technology Program (ATP) for cost-shared funding to develop this unproven technology. If successful, field emission displays could be manufactured in large quantities at reasonable prices, creating U.S. jobs and improving the nation's global position in this market dominated by foreign competitors.

By the end of the project in 1997, FED had accomplished many of its technical goals, but was unable to prevent flashover (short-circuiting) in its prototype FPDs due to problems with the vacuum. Flashover destroyed individual rows of pixels and destroyed the FPDs. Even though FED researchers received significant additional funding after the ATP-funded project concluded, they could not solve this fundamental problem. In 1999, relying on foundational knowledge gained in this project, FED Corporation redirected its research and development efforts to focus on active-matrix organic light-emitting diode (OLED)-based high-resolution microdisplays. The company changed its name to eMagin Corporation in 2000 and currently markets two high-resolution OLED-based microdisplays for use in computer monitors, headsets, and portable DVD players.

COMPOSITE PERFORMANCE SCORE

(based on a four star rating)

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Research and data for Status Report 93-01-0154 were collected during March 2004.

Flat-Panel Display Image Quality Was Poor

The basic process that enables a television or a computer monitor to display images involves lighting up thousands of tiny pixels, which are "turned on" by a high-energy beam of electrons based on a video signal. In most televisions and monitors, three pixel colors (red, green, and blue) are evenly distributed on the screen. By combining these colors in different proportions and intensities, the screen displays millions of colors and shades.

The liquid crystal display (LCD) flat-panel technology of 1993 had slow image refresh speeds, resulting in jerky movements and minimal detail. Moreover, because the contrast was poor, displays were hard to read. Most LCDs relied on a backlight, a small fluorescent tube or an array of conventional light-emitting diodes (LEDs), to supply enough light for a full white screen at all times. The average level of light emission for viewing applications is only about 25 percent of that required for a full white screen, wasting 75 percent of the energy. As a result, these LCDs consumed more power than was desirable for battery-operated products (for

example, personal digital assistants and mobile phones).

Flat-panel display researchers were trying to match or improve upon the image quality of the cathode-ray tube (CRT), the dominant technology used to generate images for computer monitors and TVs. CRT technology relies on sophisticated long glass vacuum tubes with accompanying lenses and/or a filter wheel built in. The back of the CRT display contains three electron guns (one for each color: red, green, and blue), which direct electron beams to the front of the tube. The inside front of the tube is coated with phosphor, a fluorescent material that reacts and lights up once the electron beams hit. In order to increase the screen width and height, manufacturers had to increase the length of the tube and depth of the display or monitor to give the scanning electron gun room to reach all parts of the screen. Large CRT display images lose high definition over large areas, become curved (which distorts the image), and require a glass plate up to an inch thick. CRT displays produce crisp, vibrant images, but they are heavy, bulky, and inherently analog rather than digital (consider the image quality of a movie on videotape, which is analog, compared to a DVD, which is digital).

FED Proposes Flat CRTs

The 1990s were forecast to be the “era of displays,” and flat-panel displays (FPDs) were considered to be the largest emerging electronics technology growth market, which was dominated by foreign manufacturers. FED Corporation was a start-up company that proposed to develop a technology base for field emission displays, which would be an alternative to LCDs and CRTs. Field emission displays would be flat (with minimal depth, unlike CRTs) and inexpensive, and they would display vibrant colors, with even better quality than LCDs. Each pixel would be supported by many emitters (cathodes, which were like tiny color CRT vacuum tubes) that would fire electrons simultaneously across a minute vacuum gap onto a glass layer coated with phosphor. Like conventional CRT screens, field emission displays are emissive devices, meaning they emit electrons to create light. This feature has potential benefits: high resolution, simpler construction, wide viewing angle, and low manufacturing cost, which could promote large-scale U.S. manufacturing. Field emission display devices

would use less power than LCDs and would produce images with high brightness and color.

Electronic products were a \$30 billion global market in 1994 and were becoming increasingly critical in non-electronic products such as cars and aircraft. While foreign firms dominated the display manufacturing market in 1994, FED Corporation believed that flat CRTs, based on field emission display technology, could bring a portion of the flat-screen market back to the United States. In addition to FPDs for high-definition television (HDTV), FED Corporation researchers also expected to provide technology support of field emission displays for applications such as cellular telephones, virtual reality, avionics, printing, high-speed computer network systems, and more. They intended to manufacture products using this technology in collaboration with partners and subcontractors by sublicensing the technology once it was proven. Sufficient private funds were not available due to the high technical risk of the unproven technology. Strong foreign competition increased the need to quickly develop the technology domestically. FED applied to ATP in 1993 for cost-shared funding to support this development, and funding was approved for a three-year project that began in 1994.

Prototype FPDs Have Excellent Color and Efficiency

FED Corporation researchers believed they could develop a complete working FPD within three years. Their key activities included the following:

- Develop minute diamond-coated field emitter electronics for displays, with excellent uniformity. FED had already built working, proof-of-concept diamond-coated pixels using two different vendors' equipment prior to the ATP-funded project.
- Develop vacuum spacer technology for large areas. Spacers minimize electron spread, so that electron beams go only to the pixels for which they are intended.
- Achieve adequate energy to activate high-efficiency phosphors. The phosphors light up when they are excited by electrons, creating the image.

- Develop vacuum-sealing technology to control stray electrons by removing gas (called self-gettering) as well as integrating the systems into large displays. If a vacuum could not be maintained, stray gases would interfere in electron movement.
- Integrate the components into a 7.5" diagonal prototype display system during the first 18 months of the project; then develop an experimental 21" super-video-graphics-array display that has more than one million pixels displayed in full color.

By the end of the ATP-funded project in 1997, FED researchers had successfully assembled prototype FPDs that had excellent color and energy efficiency. Image refresh speeds were suitable for a high level of detail (256 gray levels, with resolutions up to 500 lines/inch). The prototypes indicated that further work would result in even higher resolutions. The ATP-funded researchers were granted four patents for this work, received extensive press coverage, and gave a number of presentations at conferences. They achieved the following technical accomplishments: increased the image refresh speed, which allowed more detail and smoother movements; enhanced the optics around pixels for high resolution; implemented a low-cost method for manufacturing high-density electronics; reduced surface gases (water, hydrocarbons, carbon dioxide, and oxygen) in the sealed vacuum display; and improved their understanding of flashover (short-circuiting) issues. Flashover, more commonly known as arcing, is an energy-discharge phenomenon that can destroy a display's electronics. This flashover typically destroys the display and its support electronics within minutes to hours after the display is first raised to full brightness. The team added power protection circuits and other tools to prevent flashover. More work, however, was needed to prevent re-adsorption of gases.

Problems Continue with Flashover

FED continued research after the ATP-funded project ended, but technical problems plagued the developers until 1999. Researchers had not yet achieved commercially suitable video brightness without serious

high-voltage flashover. The problem started with the vacuum inside the field emission display. "You'd see the flashover phenomenon as a flash of light and then, perhaps, a line of pixels going out," said FED president, Gary Jones ("Display Vendors See Hurdles in FED Race," *Electronic Engineering Times*, July 28, 1997). Furthermore, the process to create and maintain a clean vacuum field emission display "tube" was expensive.

In 1997, FED researchers had successfully assembled prototype flat-panel displays (FPDs) that had excellent color and energy efficiency.

As an alternative to high-voltage field emission displays, FED explored using lower voltage. Low-voltage field emission displays avoided the flashover problem, but they suffered from fast phosphor burn-in (ghost images left on the display). In addition, the efficiency dropped as the voltage went down, Jones said, "...because at higher voltages, more of the [phosphor] grain is being activated. At lower voltages, more of the power is dissipated in the outer portion of the grain, so the grains degrade faster." This meant that the screensaver needed to activate quickly. Screensavers prevent burn-in of images on the display.

Company Moves to New Technology

After the ATP-funded project ended in 1997, FED began testing microdisplays based on organic light-emitting diodes (OLEDs) on silicon substrates, licensing the organic materials from Eastman Kodak. These microdisplays are viewed close to the eye, with the aid of lenses. Their benefits include high resolution, high contrast, low power consumption, and vibration tolerance. The ATP-funded project had allowed FED to build the basic technology, working with active matrix silicon substrates after FED abandoned the field emission display technology. According to Gary Jones, "ATP's support of field emission display research provided a basic technology understanding. We did incorporate pieces of it, and we learned not to do certain things. The project was valuable and helped to guide us into [microdisplays]. It came together about a year after ATP. We could not have done it without the prior ATP support." In 1999, the company began marketing high-resolution microdisplays. FED merged

with Fashion Dynamics Corporation in 2000 and changed its name to eMagin. eMagin raised approximately \$27 million in connection with the merger and continued its licensing collaboration with Eastman Kodak. In the same year they were awarded a \$3 million grant from the U.S. Air Force to develop OLED devices for use in head-mounted displays. eMagin markets two basic microdisplays, SVGA 3D and SVGA+ rev2, which are integrated into hundreds of medical, commercial, and military applications. For example, firefighters see through thick smoke by looking through a thermal-imaging camera lens to find victims, even when they are under a blanket. They can also use the lens to find the source of a fire quickly. Researchers and doctors are using the display to enhance vision for magnetic resonance imaging (MRI), endoscopic surgery, and eye surgery. The displays are also used in consumer goods, such as ultra-portable, high-quality DVD players, computers, and other electronic devices.

Conclusion

In 1993, FED Corporation's research into field emission display technology attempted to develop high-resolution flat-panel displays (FPDs) with exceptional image quality and low energy consumption. The industry was striving to develop lightweight FPDs with vibrant colors to match those of the analog cathode-ray tube (CRT). The company was awarded four patents but failed to produce marketable products, due to flashover (short-circuiting) problems that they were unable to solve. However, beginning in 1999 (two years after the ATP-funded project ended), the company was able to apply its basic display technology knowledge to its development of organic light-emitting diode (OLED) microdisplays. They have received four patents for project-related technology and have shared their project research through publications and presentations. FED Corporation changed its name to eMagin in 2000 after a merger with Fashion Dynamics Corporation. The company currently markets OLED-based microdisplays.

PROJECT HIGHLIGHTS

eMagin Corporation (formerly FED Corporation)

Project Title: Field Emission Displays Combine Benefits of Cathode-Ray Tubes (CRTs) and Flat-Panel Displays (FPDs) (Large-Area Digital HDTV Field Emitter Display (FED) Development)

Project: To develop techniques to manufacture large-scale, FPDs based on arrays of field emitters.

Duration: 3/1/1994 - 5/1/1997

ATP Number: 93-01-0154

Funding (in thousands):

ATP Final Cost	\$2,000	68%
Participant Final Cost	<u>943</u>	32%
Total	\$2,943	

Accomplishments: FED Corporation ultimately abandoned its proposed field emission display technology due to difficulties with flashover (short-circuiting) caused by stray voltage. However, the company (renamed eMagin in 2000) acquired knowledge of display technology during the project that it later applied to the development of organic light-emitting diode (OLED)-based microdisplays. With ATP funding, research and development led to the following four patents.

- "Selectively shaped field emission electron beam source, and phosphor array for use therewith" (No. 5,583,393: filed March 24, 1994; granted December 10, 1996)
- "Field emitter device, and veil process for the fabrication thereof" (No. 5,844,351: filed August 24, 1995; granted December 1, 1998)
- "Field emitter structure and method of making the same" (No. 5,587,623: filed April 3, 1996; granted December 24, 1996)
- "Field emission display devices, and field emission electron beam source and isolation structure components therefore" (No. 5,663,608: filed April 17, 1996; granted September 2, 1997)

Commercialization Status: Although field emission display technology failed, eMagin has successfully applied knowledge gained during this project to its development and marketing of OLED-based microdisplays. eMagin has commercialized two basic

microdisplays, SVGA 3D and SVGA+ rev2. These microdisplays are integrated into hundreds of medical, commercial, and military applications. For example, firefighters see through thick smoke by looking through a thermal-imaging camera lens to find victims and locate the source of a fire quickly; displays enhance vision for magnetic resonance imaging (MRI), endoscopic surgery, and eye surgery. The displays are also used in consumer goods such as ultra-portable, high-quality DVD players, computers, and other electronic devices.

Outlook: The outlook for OLED-based microdisplays is good. eMagin has successfully transferred the essential knowledge gained from field emission display technology to new applications. Although the market has been challenging in recent years, the company continues to develop and enhance its two commercial products.

Composite Performance Score: * * *

Number of Employees: 4 employees at project start, 64 as of March 1997, 24 as of December 2003.

Company:

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Publications: FED Corporation and eMagin received significant industry and financial analyst attention for work with field emission displays and OLEDs. The technologies were covered in more than 20 trade publications, such as those that follow:

- "A Closer Look... Field Emission Display Update." *Electronic Display World*, May 1994.
- "A New Type of Flat Panel Could Dethrone Matrix Displays." *Washington Technology*, June 9, 1994.
- "Start-up Steals a March on Production of FEDs." *Electronics Times*, June 23, 1994.
- "Startup claims lead in FED production." *Electronic Engineering Times*, July 4, 1994.
- "First Dedicated Field Emission Display Facility Getting Ready for Takeoff." *Photonics Spectra*, August 1994.

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- "FED Technology Takes Display Industry by Storm." *Electronic Design*, October 25, 1994.
 - "Beyond AMLCDs: Field emission displays?" *Solid State Technology*, November 1994.
 - "Flat Panel Displays: An Interesting Test Case for the U.S." *Semiconductor International*, November 1995.
 - "FEDs Show Impressive Gains." *Electronic Design News*, April 11, 1996.
 - Lieberman, David. "Display Vendors See Hurdles in FED Race." *Electronic Engineering Times*, July 28, 1997.
 - Grossman, Steve. "Head-Mounted Displays Almost Here." *Electronic Design* 48, no. 20 February 2000.
 - "Fashion Dynamics Enters Agreement and Plan of Merger with FED Corporation." *Business Wire*, March 15, 2000.
 - "Covion, eMagin Evaluate OLED Display Materials." *Electronic Chemicals News* 15, no. 8, May 15, 2000.
 - "Alliances Brighten Future For OLED Displays." *Electronic Design* 48, no. 12, June 12, 2000: 30.
 - "eMagin Receives \$3 million to Develop OLED Displays: The U.S. Air Force Has Awarded a \$3 Million Grant to eMagin." *Laser Focus World* 36, no. 9, September 2000: 73.
 - "OLED Displays Gain on LCDs." *Solid State Technology* 44, no. 10, October 2001: 22.
 - "eMagin's Colors Deepen: Firm Develops OLED Video." *Laser Focus World* 37, no. 10, October 2001: 55.
 - "eMagin to Unveil SVGA-3D OLED in Japan." *Asia Pulse*, October 31, 2001.
 - "eMagin Struggles toward OLED Production." *Laser Focus World* 38, no. 2, February 2002: 51(1).
 - "eMagin and ROHM Announce Strategic Investment; ROHM Invests \$1 million in eMagin; Companies to Explore Partnering." *Business Wire*, April 3, 2002.
 - "eMagin And VRX Announce Strategic Marketing Agreement for Interactive Electronic Games and Virtual Reality Hardware." *Business Wire*, May 22, 2002.
 - "eMagin Corp.: Company Received Funding for Contract." *Solid State Technology* 45, no. 7, July 2002: 22(1).
 - "Organic LEDs Will Receive New Materials Technologies that Will Lend Higher-Resolution." *Electronic Design* 52, no. 1, January 12, 2004: 74.
- Presentations:** FED scientists gave presentations at the following 12 academic conferences:
- "Field Emitter Displays for Future Avionics Applications," SPIE, Orlando, FL, April 1995.
 - DisplayWorks Investors Conference, February 1996.
 - "Field Emitter Displays for Future High Requirements Applications," SPIE Aerosense, Orlando, FL, April 1996.
 - "Future Consumer Applications for Field Emitter Devices," ICEE International Conference on Consumer Electronics, June 1996.
 - "High Resolution Field Emitter Displays," IEEE Lithography Workshop, August 1996.
 - EuroDisplay Workshop, Birmingham, England, September 1996.
 - "Field Emitter Based Automotive Displays," SID Conference, September 1996.
 - Michigan Display Conference, September 1996.
 - Access Avionics Conference, Los Angeles, CA, October 1996.
 - Flat Information Display Conference, San Jose, CA, December 1996.
 - SPIE Aerosense, Orlando, FL, April 1997.
 - "Field Emitter Displays," SID Conference, Boston, MA, May 1997.